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ARMY-NAVY INSTRUMENTATION PROGRAM

TRACKING PERFORMANCE AS AFFECTED BY THE POSITION OF THE ATTITUDE DISPLAY

REPORT NO. D228-421-010

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TRACKING PERFORMANCE AS AFFECTED BY THE POSITION OF THE ATTITUDE DISPLAY

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ARMY-NAVY INSTRUMENTATION PROGRAM
CONTRACT Nonr 1670(00)

This report presents work which was performed under the Army-Navy Instrumentation Program, a research and development program directed by the United States Navy Office of Naval Research. Special guidance is provided to the program from the Army Signal Corps, the Office of Naval Research and the Bureau of Weapons through an organization known as the Joint Instrumentation Working Group. The group is currently composed of the following representatives:

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The paramount objective of the ANIP program is to simplify and to improve the relationships between man (the operator) and the machine he controls to provide the man-machine complex with all-visibility operating capabilities.

The program under which this study was performed is coordinated by the Electronics Department of Bell Helicopter Company, a Division of Bell Aerospace Corporation, a Textron company, and operates under ANIP Contract Nonr 1670(00). Bell Helicopter Company is designated as industry coordinator to conduct the ANIP program with special reference to flight vehicles with steep gradient capabilities (rotary wing, VTOL, ground effect machines, etc.).

ABSTRACT

The Army-Navy Instrumentation Program has taken as one of its aims the investigation of displays which create certain identity relationships with the real world of contact vision. Thus, in presenting attitude information to enable a pilot to stabilize his aircraft in roll, pitch and yaw an effort is made to develop an encoding technique which is analagous, in a perceptual sense, to the view obtained of the world under contact flying conditions.

It is evident that if these identities are to be preserved the position of the display on the pilot's panel becomes a critical matter. One aspect of any visual percept is its location in space. Location is, of course, relative to the orientation of the perceiver's body, as well as the position of other salient features in the perceptual field.

It was the purpose of the present study to determine if the position of an attitude display with reference to the orientation of the subject and the position of the control stick affected performance.

It was found that performance was adversely affected when the display was rotationally offset 45° from a line passing through the subject's body and the control stick, as compared to the condition where the display was directly in front of the subject.

TABLE OF CONTENTS

INTRODUCTION

The Army-Navy Instrumentation Program has taken as one of its aims the investigation of displays which create certain identity relationships with the real world of contact vision (2). Thus, in presenting attitude information to enable a pilot to stabilize his aircraft in roll, pitch and yaw an effort is made to develop an encoding technique which is analagous, in a perceptual sense, to the view obtained of the world under contact flying conditions.

It is evident that if these identities are to be preserved the position of the display on the pilot's panel becomes a critical matter. One aspect of any visual percept is its location in space. Location is, of course, relative to the orientation of the perceiver's body, as well as the position of other salient features in the perceptual field.

It should not be hastily concluded, however, that in order to represent attitude in an analog sense, the display should necessarily be spatially superimposed upon the terrestrial features represented. As long as the display-control relationships are functionally equivalent, it probably makes little difference whether there is absolute spatial agreement or not. Moreover, even when this equivalence is not obtained the human organism can often adapt itself to a variable reference.

It was the purpose of the present study to determine if the position of an attitude display with reference to the orientation of the subject and the position of the control stick affected performance. Two conditions of control movement were compared. In one treatment the axis of the proper compensating control movement in roll was

geometrically parallel to the axis of display movement. Thus, if the display figure rotated to the right, the correct compensating control movement was also to the right in a plane parallel to the display movement. For this treatment, pitch control was in an axis perpendicular to display movement. If the display moved upward, the restorative control movement was pulling the stick in a direction away from the display. This treatment condition was obtained by positioning the display directly in front of the subject and having the control stick mounted between the subject and the display.

In the second treatment the control stick was again in front of the subject but the display was rotationally offset 45° to the right. This arrangement resulted in control movements which were oblique to the display movements. This required the subject to modify his reference. Instead of having a visual reference to the display, his actions had to be based upon the orientation of his own body. Instead of pushing the stick toward the display he had to learn to push it away from himself.

METHOD

Subjects

Twenty-four ROTC students from Texas Christian University served as subjects in this experiment. All were volunteers and were paid for their participation in the experiment. All were without flight training.

Apparatus

The equipment has been described in detail elsewhere (1, 3). The subject sat in an 80 x 40 x 40 inch plywood enclosure. This small room was completely darkened. On one wall of the enclosure was an 18 x 24 inch rectangular opening. Nine inches beyond this opening a 24 x 30 plastic translucent screen was mounted in a vertical position. Since the screen was larger than the opening the effect generated was that of a recess in the wall. On this screen, but on the side opposite from the subject's position, the pictures of the displays were projected. When a picture of the real world was projected on the screen, the effect was similar to the view obtained by looking through the front windshield of a moving aircraft.

Situated in the center of the enclosure was a pilot's seat and control stick assembly. It was from this position that the subject viewed the treatment window and controlled the orientation of the projected picture.

The picture could move up and down (thus simulating pitch) or rotate (simulating roll). By means of the control stick assembly the subject effected the rate of displacement of the picture with respect to these parameters of motion. A lateral movement of the stick would

cause the picture to rotate about an axis perpendicular to the surface of the screen. A leftward movement of the stick eventuated in a clockwise rotation of the picture, while a rightward movement provided counterclockwise rotation. A forward movement of the stick produced an upward translation of the picture, while an aft movement provided downward movement. The rate of movement of the picture in any direction was proportionate to the degree of displacement of the stick.

The picture was projected by means of a Beseler Master Vu-graph. The film transparency holder had been modified such that, being servo controlled by the analog computer, it could rotate (thereby projecting movement in the roll axis), or move forward and backward (projecting movement in pitch). Four by five inch film transparencies were used to produce the picture.

The analog computer (Donner Model 3300) accepted signals from the control stick and translated them into pitch and roll movements of the film holder. In addition, the computer also received signals from a cam-driven disturbance source. A separate disturbance was provided for the roll and pitch channels. The cams rotated at 1 rpm; consequently, the programmed disturbance repeated itself during each minute of testing. The programs were selected as producing disturbances similar to those encountered by a helicopter in turbulent air.

A temporal lag was introduced between the reception of signals from the control stick and the computer action. These periods roughly corresponded to the control lags for pitch and roll in a helicopter.

Error scores (momentary error integrated through time) were obtained for both control parameters. These were based upon absolute errors, i.e., accumulated irrespective of sign. In roll a momentary

clockwise error of a given magnitude would produce an equivalent absolute error as a counterclockwise error of the same magnitude. Similarly, in pitch, "up" errors were accumulated with "down" errors. Error sources for pitch and roll were continuously enregistered on separate single-channel Sanborn (Model 151) recorders.

In addition to errors an index of subject output was obtained. When the input of the subject's response on the roll channel exceeded a prescribed accelerative value, an automatic counter was energized. Thus, in the course of testing, the frequency of such responses was accumulated. This gave a rough indication of the amount of work the subject was doing to control for roll. A similar circuit and counter was provided for the pitch channel.

Four pictures or displays were used in connection with this experiment. These are shown in Figure 1. The displays differed in stimulus redundance and represented different ways of encoding earth and sky. Display "A" was a monochromatic photograph of the real world with a well-defined horizon. Display "B" was a converging grid line display with the sky represented as blue and the earth as reddish brown. Display "C" was similar to "B", except that the picture was achromatic. Display "D" showed the intersection of two perpendicular lines forming a T. These displays were represented on the transparencies projected on the translucent screen and, in effect, the subject "flew" these pictures.

Pre-Test Procedure

All pre-test training was given with Display "A". A subject was asked to enter the enclosure and to seat himself in the pilot's seat

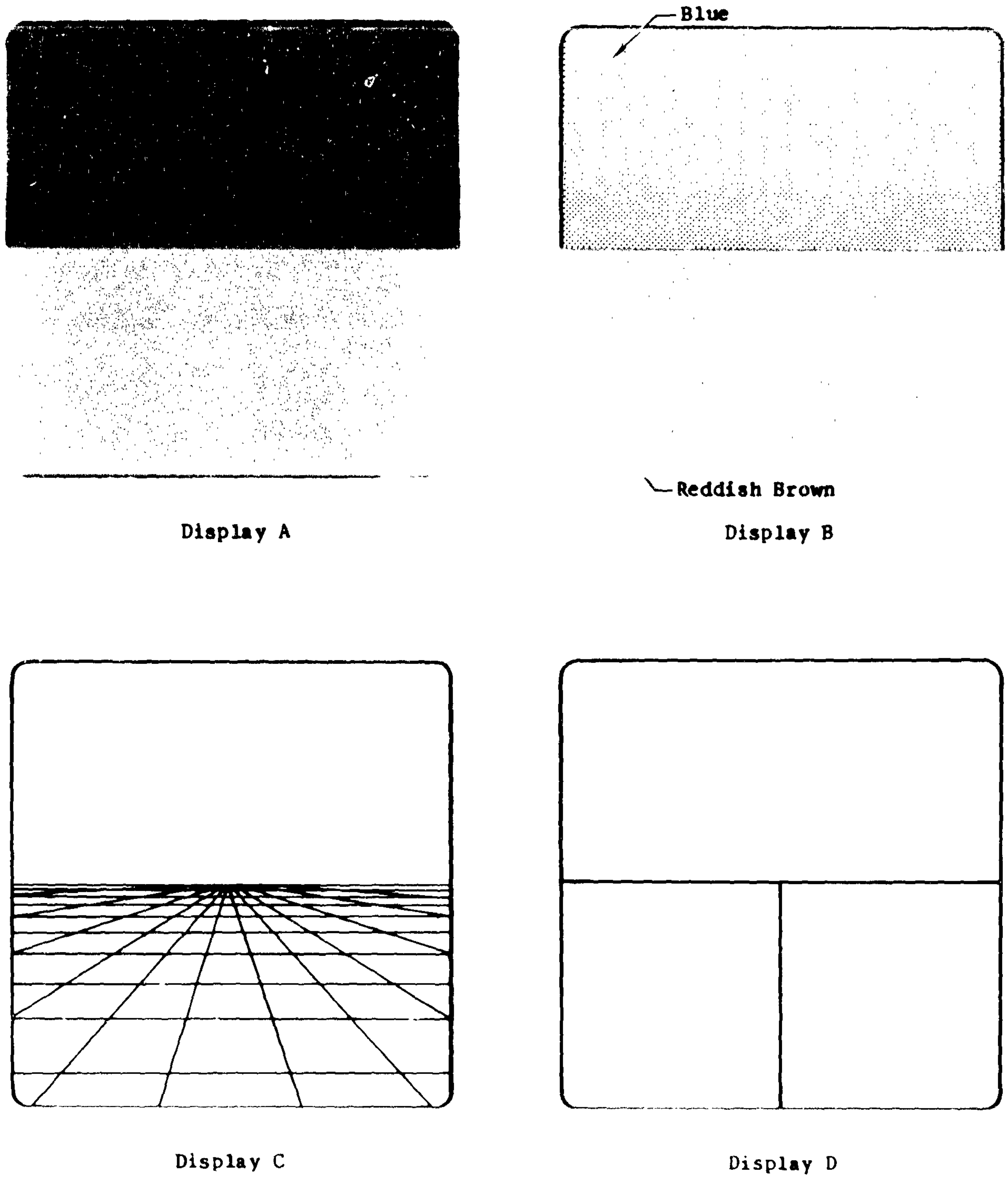

Figure 1. Displays used in Experiment

provided. Display "A" was placed in the film transparency holder, the computer and disturbance signals were energized and the projector light was turned on. The subject was shown how the display appearing on the translucent screen would drift away from "straight and level" due to the action of the disturbance and the position of the stick. He was then shown how to correct for drift by moving the control stick. He was instructed to try to keep the display straight and level at all times. Each subject was given exactly 10 minutes practice trying to hold Display "A" in the correct position. For any particular subject the position of the pilot's seat and control stick assembly during pre-testing did not vary from the position used later in testing.

Test Procedure

Each subject was tested on three consecutive days. A day's testing consisted of tracking (holding straight and level) ten minutes on each of the four displays. Each subject received a different order of display presentation. The order of presentation did not change from day to day for any given subject, however.

A five-minute rest period was given between each ten-minute tracking period.

For half of the subjects (Group I) the orientation of the pilot's seat and control stick assembly was such that the translucent window appeared directly in front of the subject. In the case of this group the axes of display movement were parallel to the axes of control movement.

For the remaining subjects (Group II) the seat and stick assembly was rotated counterclockwise 45° from the orientation enjoyed by

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TABLE I

ORDER OF DISPLAY PRESENTATION

	SUBJECT	Day 1	Day 2	Day 3
	1	A B C D	A B C D	A B C D
	2	A C D B	A C D B	A C D B
	3	A D B C	A D B C	A D B C
	4	B A D C	B A D C	B A D C
	5	B C A D	B C A D	B C A D
Group I	6	B D C A	B D C A	B D C A
	7	C A B D	C A B D	C A B D
	8	C B D A	C B D A	C B D A
	9	C D A B	C D A B	C D A B
	10	D A C B	D A C B	D A C B
	11	D B A C	D B A C	D B A C
	12	D C B A	D C B A	D C B A
	13	A B D C	A B D C	A B D C
	14	A C B D	A C B D	A C B D
	15	A D C B	A D C B	A D C B
	16	B A C D	B A C D	B A C D
	17	B C D A	B C D A	B C D A
Group II	18	B D A C	B D A C	B D A C
	19	C A D B	C A D B	C A D B
	20	C B A D	C B A D	C B A D
	21	C D B A	C D B A	C D B A
	22	D A B C	D A B C	D A B C
	23	D B C A	D B C A	D B C A
	24	D C A B	D C A B	D C A B

RESULTS

Two indices of performance were obtained on each of the pitch and roll control channels. There were absolute error (momentary error accumulated through time, irrespective of direction) and subject output (frequency of control movements exceeding a prescribed acceleration). For expository purposes absolute error is designated as $\int |e|$ and subject output by the symbol W.

Mean absolute errors in pitch for groups and displays are shown in Table II. The differences between displays are small and without statistical significance. The difference between groups favors Group I. This difference is significant at the 99% level of confidence by the t test, as shown in Table III. In this analysis display differences are ignored.

Mean absolute errors in roll are given in Table IV. The largest mean absolute error score occurred in the use of Display D. The difference is not significant, however. Between groups the difference again favors Group I. This difference is significant at the 95% level of confidence by the t test as shown in Table III.

TABLE II

MEAN ABSOLUTE ERROR $\int |e|$ IN PITCH FOR GROUPS AND DISPLAY TREATMENTS

	DISPLAY				
	A	B	C	D	TOTAL
Group I	68.5	61.0	60.5	71.0	65.25
Group II	90.5	84.2	86.0	89.3	87.50
Total	79.50	72.60	73.25	80.15	76.37

TABLE III

SUMMARY OF t SCORES BETWEEN GROUPS FOR THE DEPENDENT VARIABLES

	MEANS		
Measurement	Group I	Group II	t
$\int \lvert e \rvert$ -Pitch	65.3	87.5	3.28
$\int \lvert e \rvert$ -Roll	34.8	62.8	2.30*
W -Pitch	46.3	42.8	1.70
W -Roll	39.5	37.5	0.87

99% level of confidence
* 95% level of confidence

TABLE IV

MEAN ABSOLUTE ERROR $\int \lvert e \rvert$ IN ROLL FOR GROUPS AND DISPLAY TREATMENTS

	DISPLAY				
	A	B	C	D	TOTAL
Group I	37.0	28.5	33.0	40.5	34.75
Group II	55.0	68.0	60.5	67.5	62.75
Total	46.0	48.25	46.75	54.0	48.75

The means for frequency of accelerations exceeding a prescribed value are shown in Table V for pitch. Again the differences due to display are small and without significance. By this method of measurement Group II did not appear to work as hard as Group I. This may, in part, account for the absolute error differences shown in Table II. It will

be seen, however, from Table III that the difference between groups in pitch for the W measurement was not significant.

The means for groups and displays on the W measurement in roll are given in Table VI. None of the differences between displays or between groups are large. In Table III the t test of the difference between groups is shown but no significant differences were found.

TABLE V

MEAN FREQUENCY OF RESPONSES HAVING AN ACCELERATION IN EXCESS OF A PRESCRIBED VALUE (W) IN PITCH FOR GROUPS AND DISPLAY TREATMENTS

	DISPLAY				
	A	B	C	D	TOTAL
Group I	47.1	45.7	48.7	43.8	46.3
Group II	46.9	41.4	39.3	43.5	42.8
Total	47.0	43.5	44.0	43.6	44.5

TABLE VI

MEAN FREQUENCY OF RESPONSES HAVING AN ACCELERATION IN EXCESS OF A PRESCRIBED VALUE (W) IN ROLL FOR GROUPS AND DISPLAY TREATMENTS

	DISPLAY				
	A	B	C	D	TOTAL
Group I	36.4	40.2	39.8	41.6	39.5
Group II	37.0	35.5	39.6	37.9	37.5
Total	36.7	37.8	39.7	39.7	38.5

Discussion

The results strongly suggest that performance will be adversely affected if the display of attitude is rotationally displaced with reference to the position of the pilot and the control stick.

It does not follow, however, that lateral or vertical displacement (without rotational reorientation) of the display would have the same debilitating effect since the directional relationship of display to control would not be modified. Since there are many available positions in the cockpit (between the pilot's legs, offset to the right or left) which could prove more convenient locations than directly in front of the pilot, the effect of such displacement should be investigated.

SUMMARY

The results of an experiment are reported in which subject performance as it relates to the position of the attitude display was evaluated. It was found that performance was adversely affected when the display was rotationally offset 45° from a line passing through the subject's body and the control stick, as compared to the condition where the display was directly in front of the subject.

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